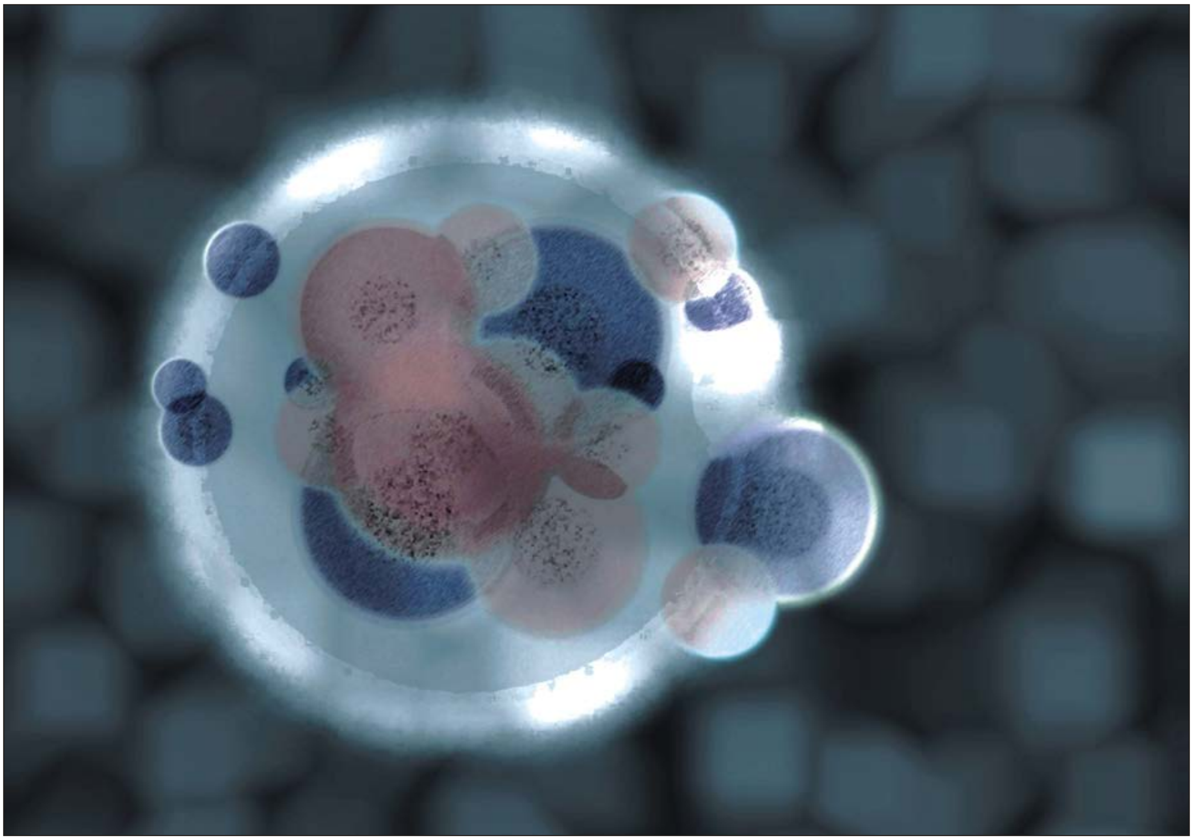

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The Effects of Different Forest Conditions on Soil Macroporosity and Soil Hardness: Case of a Small Forested Watershed in Japan

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Abstract: The effects of different forest conditions on soil macroporosity and soil hardness was investigated in natural and artificial forests in the Ehime University Forest, Japan. Eleven treatments were established based on forest type and stand density of Japanese cedar and cypress. Stand density was indicated by relative yield index (Ry), function of standing volume and stem density. General Linear Model Analysis of SPSS was used to test whether differences in soil macroporosity and soil hardness were statistically significant in different treatments, followed by Tukey HSD in case of significance. Results showed that in topsoil, natural forest, Japanese cedar and cypress with Ry comprised between 0.50 and 0.60 had the highest means of soil macroporosity. The lowest means were found in Japanese cedar with Ry: 0.70-0.80 and Japanese cedar and cypress with Ry: 0.80-0.95. Soil hardness did not have notable differences among the treatments except for Japanese cedar and cypress with Ry: 0.80-0.95 where means were higher than in others. In general, subsoil did not differ in areas with different forest conditions. These results suggest that thinning operations are needed in areas with high Relative yield Index (Ry > 0.70, corresponding to excessive density forest) where poorer soil properties were found.

Key words: Forest type, stand density, soil physical properties

INTRODUCTION

Forest soils have a high percentage of macropores through which large quantities of water can move. Some macropores result from structural pores and cracks in the soil; others develop from old root channels or from burrows and tunnels made by insects, worms and other animals (Fisher and Binkley, 2000) and influence soil water infiltration and aeration (Lee and Foster, 1991). Majority of saturated flow takes place through macropores which are preferentially removed during compaction (Hatchell *et al.*, 1970). Other findings showed that macroporosity was a much more sensitive indicator of soil compaction than was bulk density and others (Hill *et al.*, 2003).

Many researchers found that forest practices and forest harvests can cause damages to the soil characteristics (Dyck, 1994; Amaranthus, 1996) especially by heavy operations (Meurisse, 1995; WSU, 1991) or having ground-based skidding (Jakobsen and Moore, 1981). It has been reported that the type of management practice and period of time under that management will determine the actual macroporosity of a soil (Elliot and Coleman, 1988). On the other hand, some authors argue that there is so far little understanding by many loggers and some foresters about forest soils and the impact that timber harvesting and other forest practices have on them (Kimmins, 1997). It is apparent that there is a need to understand the soil impacts resulting from forest management activities among forest land-owners, resource managers and others involved in forest management. Although many researches reported the impacts of forest thinning operations, this study provides reasons that demonstrate the alteration of forest soils without appropriate forest management operations.

Artificial forest plantations in the study area consisted mainly of Japanese cedar (*Cryptomeria japonica* D. Don, Taxodiaceae) and Japanese cypress (*Chamaecyparis obtusa* (Sieb. and Zucc.) Endl. Cupressaceae). Although many studies have been conducted on the performance of Japanese cedar and Japanese cypress as plantation tree species and their influence on forest ecosystems, little is known about their

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impact on soil physical properties especially on soil macroporosity and soil hardness.

In this study, soil macroporosity and soil hardness were compared in sites with different forest conditions. The collective term forest conditions refers to stand density of artificial plantations indicated by relative yield index (Ry) which was calculated from stand volume and stem density and forest species consisting of natural broadleaved forests (broadleaves), Japanese cedar and Japanese cypress.

Relative yield index was chosen as an indicator of forest conditions based on Ando (1982) stipulating that Ry is among the best tools to describe forest stands and prescribe appropriate forest management. Furthermore, this method is recognized and applied throughout Japan under the Ministry of Agriculture, Forestry and Fisheries of Japan. Soil macroporosity was calculated from laboratory measurements on undisturbed samples taken from the field and soil hardness was determined from soil survey.

The main objectives of this study were to establish the relationship between forest conditions represented by stand density based on relative yield index, forest type (natural or artificial forest), forest species and some soil physical properties such as soil macroporosity and soil hardness.

MATERIALS AND METHODS

Study site: The study was conducted in the Ehime University Forest located 18 km northeast of Matsuyama City in Ehime Prefecture (Shikoku Island, Japan). It contains warm to cool temperate natural forests and plantations of Japanese cedar and cypress. The highest rainfall amount recorded was in 1980 and 1993 with 2673.6 and 2673 mm, respectively and the lowest was in 1994 and 2002 with 969 and 943 mm, respectively. The highest annual average temperature was in 1990 with 13.5°C and the lowest in 1980 with 11.3°C. The study area (Fig. 1) was confined to a small watershed of 191.46 ha; the elevation ranges from 515 to 950 m above sea level, with slopes ranging from 30-50% (Ehime University Forest, 2002). Preliminary results (Razafindrabe, 2004) from the same site showed that among the forest physical attributes examined, slope angle and slope direction did not have any direct effect on soil physical properties within the same study site at the 0.05 level of significance. Other studies reported findings showing significant differences among soil properties depending in which slope direction they were sampled (e.g., Cerdâ, 1997). Our preliminary study did not have similar results. In addition, most of the plots were located in steep slopes, reducing the slope variability. Though stand age range was important (from 10 to 120 year-old), the only significant difference among the soil properties at the same level of significance was found in plots more than 90 years old and less than 90 years old, corresponding, respectively to natural forests and artificial forests, respectively. This justifies the focus on forest species and forest operation variables indicated by relative yield index.

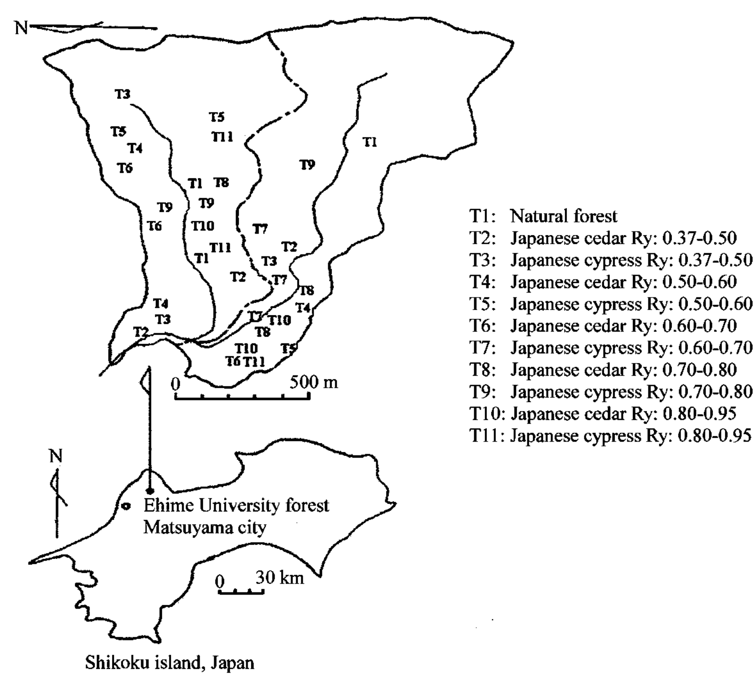

Fig. 1: Study area, first and second subdivision of the Ehime University Forest

Table 1: Description of the treatments

Treatments	Characteristics
T1	Natural forest
T2	Japanese cedar Ry : 0.37-0.50
T3	Japanese cypress Ry : 0.37-0.50
T4	Japanese cedar Ry : 0.50-0.60
T5	Japanese cypress Ry : 0.50-0.60
T6	Japanese cedar Ry : 0.60-0.70
T7	Japanese cypress Ry : 0.60-0.70
T8	Japanese cedar Ry : 0.70-0.80
T9	Japanese cypress Ry : 0.70-0.80
T10	Japanese cedar Ry : 0.80-0.95
T11	Japanese cypress Ry : 0.80-0.95

Table 2: Models for the determination of Relative yield Index (Ry) for Japanese cedar and Japanese cypress species[a]

Japanese cedar	Japanese cypress
$Ry = V / V_{Rf}$	$Ry = V / V_{Rf}$
$V = (0.074343H^{-1.388481}+5065.0H^{-2.900328}/N)^{-1}$	$V = (0.053887H^{-1.183794}+7663.1H^{-3.201510}/N)^{-1}$
$V_{Rf} = (0.074343H^{-1.388481}+5065.0H^{-2.900328}/N_{Rf})^{-1}$	$V_{Rf} = (0.053887H^{-1.183794}+7663.1H^{-3.201510}/N_{Rf})^{-1}$
$\log N_{Rf} = 5.38221-1.51185\log H$	$\log N_{Rf} = 5.992602-2.017716\log H$

[a] The model was elaborated from surveys on the same area in Japan, approved and applied by the Ministry of Agriculture, Forestry and Fisheries of Japan (Ando, 1982), where: Ry: Relative yield index; V: Standing volume (m^3/ha); V_{Rf}:Standing volume in maximum density (m^3/ha); H: Tree height (m); N: Stem density (trees/ha); N_{rf}: Stem density in maximum density (trees/ha)

Model and treatment description: Eleven treatments with different forest conditions were delineated within the first and second subdivisions of the University forest based on forest type/species composition and relative yield (Ry) (Table 1). According to Ando (1982), Ry varies from 0.1-indicating very sparse forests or with high stem density but with very low standing volume, to 1.0-corresponding to the fully-packed stand with very high density. Two models (Table 2) for Japanese cedar and Japanese cypress were used to calculate relative yield index for each area.

In this study, low Ry values show mature stands having experienced a high thinning intensity and gradually reducing as Ry values increase. Relative yield index close to 0.80 and 0.90 represent stands without any previous thinning operations conducted. Relative yield values in the study are extracted from the density management curve re-arranged and developed by Ando (1982) based on stem density (trees/ha), stand volume (m^3/ha), tree height (m) and DBH diameter at breast height (cm). Forest type/species include natural broadleaves stands, *Cryptomeria japonica* (Japanese cedar) and *Chamaecyparis obtusa* (Japanese cypress) plantations. Forest age ranged from 10-80 years for artificial coniferous forest plantations while the natural broadleaves were much older with an age range of approximately 85-120 years.

Soil sampling and analysis: Three sampling sites were delineated for each treatment and 3 sampling points were identified for each site, making a total of 99 samples for topsoil (0-20 cm) and the same number for subsoil (20-40 cm). Soil core samples were taken in April and May 2004, with a sharp-edged steel cylinder of 112.8 mm diameter by 40 mm height on midslopes according to each treatment. Soil hardness was determined by using a manual push cone penetrometer.

The core samples were analyzed for total porosity, microporosity and macroporosity based on the method of Kawada and Kojima (1976). Calculation of total porosity was based on the particle and bulk densities method; microporosity was determined after drying the samples using porous ceramics for 24 h, subtracting this volume by the oven-dried soil volume and divided by the total sample volume. Macroporosity was calculated as the difference between total porosity and microporosity.

Data analysis: All data summaries and statistical analyses were calculated using the Statistical Package for the Social Sciences (SPSS, ver., 11.0). Attributes of macroporosity, infiltration rate and soil hardness were standardized prior to statistical analyses. General Linear Model Analysis of variance (ANOVA) was used to test whether the different soil water properties investigated were statistically significant in different treatments. In case of significance, mean values were compared using Tukey Honestly Significant Difference at $p<0.05$.

RESULTS AND DISCUSSION

Case of topsoil (0-20 cm): Soil macroporosity varied notably within treatments. As shown in Table 3 and Fig. 2, the highest values of soil macroporosity were found in T1, T4 and T5 (52.95, 49.70 and 45.48%) representing natural forest, Japanese cedar and cypress with relative yield index comprised between 0.50 and 0.60,

Table 3: Main effects of forest conditions on soil macroporosity and soil hardness for topsoil[a]

Treatments	Characteristics	Macroporosity (%)	Soil hardness (kg cm^{-2})
T1	Natural forest	52.9589a	5.1444d
T2	Japanese cedar Ry : 0.37-0.50	44.9300abc	5.8444bcd
T3	Japanese cypress Ry : 0.37-0.50	36.7611cde	6.8111b
T4	Japanese cedar Ry : 0.50-0.60	49.7089ab	5.9111bcd
T5	Japanese cypress Ry : 0.50-0.60	45.4889ab	5.2667cd
T6	Japanese cedar Ry : 0.60-0.70	43.5322bcd	5.6222bcd
T7	Japanese cypress Ry : 0.60-0.70	35.8022def	6.8778b
T8	Japanese cedar Ry : 0.70-0.80	34.6111ef	6.5556bc
T9	Japanese cypress Ry : 0.70-0.80	35.3156def	6.5778bc
T10	Japanese cedar Ry : 0.80-0.95	28.2822f	9.5778a
T11	Japanese cypress Ry : 0.80-0.95	29.0144ef	8.8222a
F-value		21.506	23.426
p-value		0.000	0.000

[a]Means within a column followed by the same letter(s) are not significantly different based on Tukey's test (0.05 level)

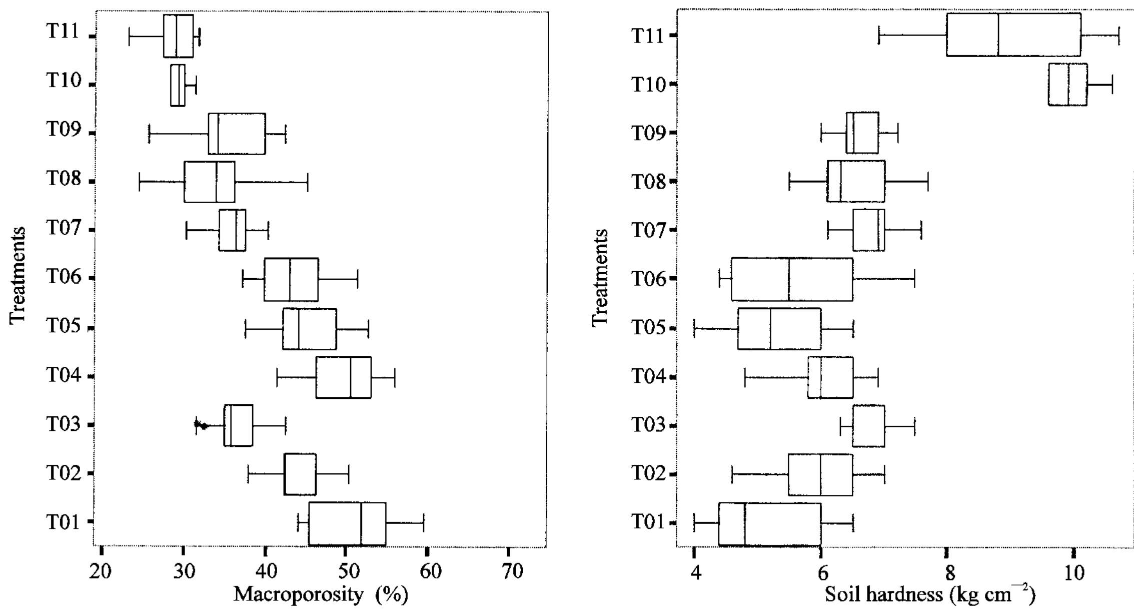

Fig. 2: Topsoil macroporosity and soil hardness in different treatments in the study area. Median and extreme values are presented

respectively. The lowest means of macroporosity were found in T8, T10 and T11 (34.61, 28.28 and 29.01%) representing Japanese cedar Ry: 0.70-0.80 and Japanese cedar and cypress plantations with Ry 0.80-0.95 ($F = 21.50$; $p<0.05$), respectively. Soil hardness did not have notable differences among the treatments except for T10 and T11, (respectively Japanese cedar and cypress with Ry 0.80-0.95) where means of soil hardness were higher (9.57 and 8.82 kg m^{-2}, respectively) than in other treatments. This means that soils in this area are physically harder than in other areas.

Case of subsoil (20-40 cm): Unlike the case of topsoil variables, subsoil variables did not differ much among the treatments. Soil macroporosity differed in areas having higher Ry such as T11, T10 and T9 (Japanese cedar and cypress plantations with Ry 0.80-0.95 and Japanese cypress Ry: 0.70-0.80, respectively) and also in some areas such as T6 (Japanese cedar Ry: 0.60-0.70) and T3 (Japanese cypress Ry: 0.37-0.50) with lower relative yield (Table 4 and Fig. 3). These areas showed lower values of macroporosity ($F = 9.78$; $p<0.05$) compared to the others. These results mean that although some differences were identified in some treatments, subsoil variables were in general not significantly affected by the different forest conditions. There was no significant difference for the variable soil hardness, except a slight significance ($F = 3.80$; $p<0.05$) for T1 (natural forest) where the subsoil was showing less hardness (8.23 kg cm^{-2}) than in other treatments.

These results indicate that infiltration rate and soil macroporosity were higher in areas having more sunlight

Table 4: Main effects of forest conditions on soil macroporosity and soil hardness for subsoil[a]

Treatments	Characteristics	Macroporosity (%)	Soil hardness (kg cm^{-2})
T1	Natural forest	46.14667a	8.233333b
T2	Japanese cedar Ry : 0.37-0.50	41.96abc	10.51111a
T3	Japanese cypress Ry : 0.37-0.50	35.26222bcd	10.46667a
T4	Japanese cedar Ry : 0.50-0.60	45.25111ab	10.06667ab
T5	Japanese cypress Ry : 0.50-0.60	42.06111abc	9.844444ab
T6	Japanese cedar Ry : 0.60-0.70	30.83667d	10.22222a
T7	Japanese cypress Ry : 0.60-0.70	34.14cd	10.13333a
T8	Japanese cedar Ry : 0.70-0.80	41.70444abc	10.02222ab
T9	Japanese cypress Ry : 0.70-0.80	30.933333d	10.06667ab
T10	Japanese cedar Ry : 0.80-0.95	28.13222d	11.25556a
T11	Japanese cypress Ry : 0.80-0.95	27.97556d	11a
F-value		9.789	3.809
p-value		0.000	0.000

[a]Means within a column followed by the same letter(s) are not significantly different based on Tukey's Test (0.05 level)

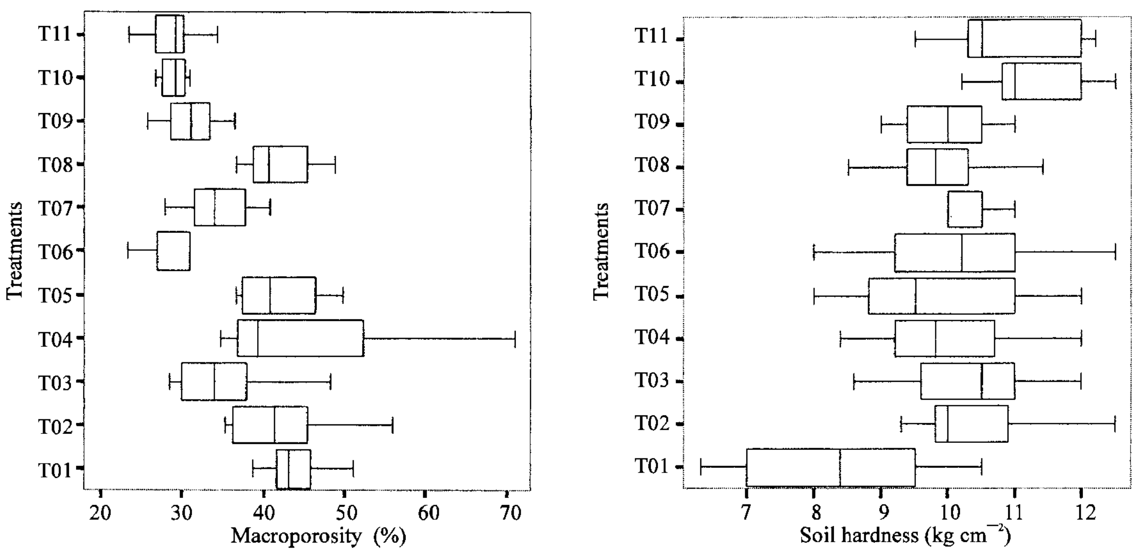

Fig. 3: Subsoil macroporosity and soil hardness in different treatments in the study area Median and extreme values are presented

penetration to the forest floor due to the lower stand density (Ry: 0.50-0.60) and resulting to the development of understorey plant growth (Shiozaki, 1977). Previous thinning operations set back succession and the remaining trees grow better because moisture and soil nutrients are more readily available (Jones *et al*., 1994).

Areas with high relative yield (Ry) almost reaching the maximum value of 1.0 characterizing a fully packed plantation, with a very high density and where thinning operations have not been conducted showed less infiltration rate and soil macroporosity than other treatments. Also, soils were found much harder in this area than in others. However, areas with the lowest stand density did not have the highest infiltration rate (T2 and T3 representing Japanese cedar and cypress plantations with Ry: 0.37-0.50) although enough sunlight was present in the stand; maybe due to the excessive thinning operations or heavily damaged by natural disasters, creating too much distances between trees and destabilizing the whole stand. Another reason to explain the differences among the treatments is the abundance of organic materials as substrate that might have favored higher microbial activity and organic matter decomposition (Fisher and Binkley, 2000). Other findings showed that the modification of forest litter composition as substrate for microbial decomposition led to enhance organic matter turnover (Berg, 2000). This could be one of the contributing effects of thinning operations on soil physical properties and particularly on infiltration rate since thinning operations have enhanced the secondary growth of other species at the ground level that result to a more diverse composition of organic materials compared to the unthinned forest. The available moisture and abundance of litter can also influence the presence of earthworms whose burrows contribute to macroporosity and so influence water infiltration and aeration (Lee and Foster, 1991). Moreover, macropores are important for soil aeration and open soil structure that will define the root and microbial environments as well (Sparling and Schipper, 1998). Soils with lower soil macroporosity represent more compacted soils, illustrated by high values of soil hardness in the study.

Another possibility is the high organic matter content in thinned plots (Ry: 0.50-0.60 or Ry: 0.37-0.50) which affects aggregate development and creates more macropores (Mapa, 1995). In addition, since litter layers are present in most areas with lower Ry rates, run-off is delayed and there is more time for infiltration to take place, increasing the water intake of such soils (Heermann and Duke, 1983). In the opposite case, a decrease in macropores restricts the aeration and infiltration of the rooting environment, affecting the penetrability of roots since majority of saturated flow takes place through macropores, which are preferentially removed during compaction. An alternative of originally similar soil characteristics can be imaginable between managed and unmanaged forests, however, due to soil compaction macroporosity had reduced due to absence or less understorey vegetation (Arnup, 1998) and reduced macropores reduce infiltration rate.

Findings in this study can further help both foresters and soil and water conservationists to subtract from the forest the best production with less harm to the soil environment. Also, according to Papadopol (2000), through regular stand density control, risks due to climatic variability to existing stands can be decreased while higher quality timber can be brought in the economic circuit.

This study may especially help engineers to be aware of the need of combination of wood production and soil and water conservation through regular stand density control, essential step toward sustainable production.

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